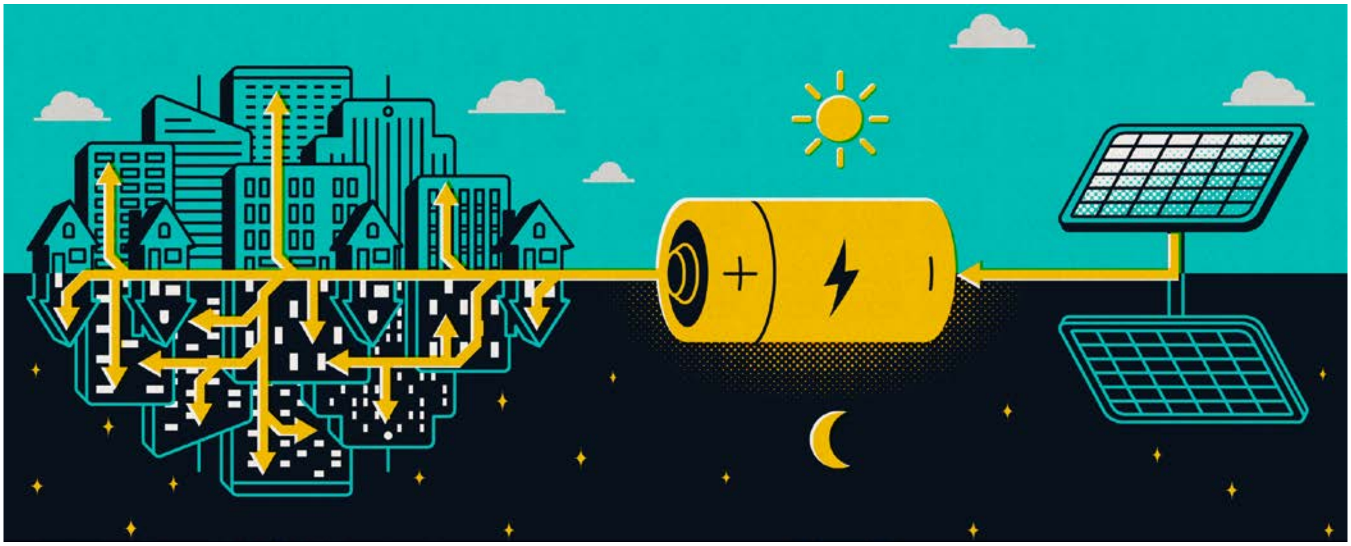
Storing in Bulk



The Need for Large-Scale Energy Storage Grows, but the Business Case Remains Uncertain

By Brent Barker

Energy storage on the electricity grid has been around since the 1880s when Thomas Edison used lead-acid batteries to store power for the nighttime illumination peak. At the time, Edison's direct current grid extended no more than a few city blocks in lower Manhattan, and nearly all the electric demand was for lighting.

The first bulk energy storage system in the United States was a pumped hydroelectric storage facility, commissioned in 1929 in Connecticut. Pumped hydro consumes electricity to move water from a lower reservoir into an upper reservoir. Then, when power is required, water released by the upper reservoir flows down through a hydroelectric turbine to generate electricity. The technology offers large capacity discharge, fast response, and economies of scale. Over the next 50 years, more than 20 gigawatts of pumped hydroelectric storage were installed in the United States, and more than 127 gigawatts worldwide. Today it accounts for about 98% of bulk electricity storage globally.

In the 1980s and 1990s, however, deployment in the U.S. slowed to a halt as a result of restrictions on land and water use. "Utilities that have it, love it, because it provides flexible power to help balance their grids," said Brittany Westlake, a scientist in EPRI's Energy Storage and Distributed Generation Program. "But the best sites in the U.S. are already taken, and costs for construction and permitting for new sites can be prohibitive." The most recently built facility in the U.S. went into service in Georgia in 1995.

The Bath County Pumped Storage Station in Virginia's Allegheny Mountains has a capacity of more than 3,000 megawatts. Photo courtesy of Jeffrey G. Ocampo, Dominion Energy.

For more than two decades, the scientific and engineering communities have been on a wide-ranging, determined search for viable alternatives to pumped hydro. The search has intensified as intermittent renewable generation has grown and the grid has become more complex, calling for the operational flexibility and support that bulk energy storage can provide.

The Strategic Role of Bulk Energy Storage

Bulk storage offers grid operators two essential attributes: hundreds of megawatts of power capacity and an ability to deliver electricity continuously for many hours.

"Today, the biggest drivers for bulk storage are the need to integrate intermittent, utility-scale renewables and the potential to defer investment in transmission and distribution infrastructure," said Matt Pellow, a scientist in EPRI's Energy Storage and Distributed Generation Program. "Utilities are saying, 'My wind resources are blowing at night, which is not when I need them. How do I maximize my returns on those assets?' This thinking leads inevitably to storage."

Recognizing the forecasts for significant wind and solar investment, regulators and grid operators are eager to couple renewables with bulk storage to maximize value and support grid integrity. In 2013, the California Independent System Operator estimated that it needed as much as 6,000 megawatts of electric capacity to cover the loss of solar to meet the evening peak. It predicted that the gap would grow to more than 13,000 megawatts by 2020. The same study projected over-generation in the middle of the day, pointing to a possible opportunity for energy storage to shift midday generation to the evening peak. Although natural-gas-powered generation is capable of providing this capacity, that approach runs counter to the state's renewable energy targets.

As utilities review supply and demand forecasts throughout their service territories, they recognize the implications of bulk storage for cost-effective, reliable power delivery. "If they forecast a need for additional transmission capacity, they are faced with an expense that has to be passed along to ratepayers," said Pellow. "This is a potential opportunity for storage to reduce the cost of meeting that need, but only if it costs less than building transmission lines. In industry meetings, the issue of deploying storage for grid upgrade deferral is moving from an interesting discussion topic to serious consideration. The cost of storage, though declining, is still significant, so careful analysis is required to establish the business case."

Installing bulk storage downstream from a nearly overloaded transmission node could defer costly infrastructure investment for years. Since the highest loads on a node typically occur only a few days or a few hours per year, even a small amount of storage could provide enough capacity to delay—or conceivably eliminate—large and costly upgrades.

Transmission congestion can hinder delivery of least-cost energy from remote generation. Adding storage at strategic locations can potentially facilitate cost-effective power delivery to rapidly growing markets.

Increasingly, bulk storage systems will be called upon to provide direct and ancillary electricity services, such as:

- **Load leveling**: Smoothing load by absorbing energy from or injecting energy into the grid.
- **Ramping support**: Providing supplemental power during startup and shutdown of baseload generation or when solar or wind generation output fluctuates.
- **Energy arbitrage**: Shifting energy production from low-value to high-value periods.
- **Firm capacity**: Guaranteeing availability of backup energy to compensate for dips in renewable energy production.
- **Spinning reserves**: Grid-connected reserve power ready for instantaneous delivery.
- **Non-spinning reserves**: Reserves not connected to the grid but able to deliver power within minutes.

- **Black start**: Bringing a generation plant from shutdown to a specified power level within a specified time, without support from transmission lines.
- **Frequency regulation**: Providing short-term power adjustments to help maintain system frequency within required levels.
- **Voltage support**: Producing or absorbing reactive power to maintain a specific grid voltage.

A single storage system may be able to provide multiple services simultaneously.

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Bulk Storage Concepts and Requirements

For electricity to be stored, it must be converted to a different form of energy. When electricity is needed, the process is reversed. For example, batteries store electricity by using it to drive a chemical reaction, which is later reversed to provide electricity. With pumped hydro storage, electricity is used to pump water uphill to an upper reservoir, converting it to potential energy. To reverse the process, water is allowed to flow to the lower reservoir through a turbine, which converts the potential energy back to electrical energy. Compressed air energy storage systems use electricity to compress air and store it in a reservoir, either an underground cavern or aboveground pipes and vessels. When electricity is needed, the compressed air is heated, expanded, and directed through a conventional turbine-generator to produce electricity.

Technology developers, utilities, and other stakeholders are actively investigating diverse forms of storage for inexpensive, efficient options. Technologies being considered include flow batteries, which are commercialized in limited applications, as well as adiabatic compressed air energy storage and liquid air storage, which are in early commercialization. Molten salt thermal storage and advanced rail energy storage are also under development, but the economics for these technologies are less certain.

"The technology portfolio, and timeline to commercialization, will depend on who can lower their costs, by how much, and when," said Pellow.

Today, there are only two technologies—pumped hydro and compressed air energy storage—with decades of operational experience providing energy storage that:

- Delivers energy for 6 or more hours at maximum-rated output.
- Charges and discharges at power ratings ranging from 10 to hundreds of megawatts.

Geology and geography have held back the expansion of traditional compressed air energy storage, which is deployed globally at just two facilities—one in Germany (installed in 1978) and one in Alabama (installed in 1991). Historically, large underground salt caverns have been required to store the compressed air, restricting application in the U.S. to the Gulf Coast region. More recently, porous rock and abandoned underground natural gas reservoirs are being investigated as possible sites, but these are often located far from load centers and are therefore less cost-effective.

While pumped hydro and compressed air energy storage provide large-scale, long-duration storage, batteries and flywheels—storage technologies more commonly deployed in recent decades—are particularly good at providing power on very short notice for shorter durations. However, large-scale, long-duration energy shifting is increasingly necessary on a high-renewables grid.

Emerging Technologies

Some innovation in bulk storage focuses on a rethinking of compressed air energy storage. Traditional compressed air storage requires heating of the released air, usually by natural gas, before it is run through a turbine-generator. Alternatively, with adiabatic compressed air energy storage, thermal energy produced during compression is stored in a material such as a molten salt and then used during expansion. The adiabatic version of compressed air storage is fuel-free, reducing costs and eliminating combustion-related emissions.

In an adiabatic compressed air energy storage system developed by Toronto-based Hydrostor, air is compressed and stored in a constructed cavern at the bottom of a 1,200-foot-deep well. Water drawn from a nearby lake or pond fills the well, and its weight keeps the air pressurized in the underground cavern. The heat released from compressing the air is stored. When power is required, a valve is opened, and the compressed air exits the chamber, expands, and drives a turbine-generator. Hydrostor believes that this configuration will allow compressed air storage to be built in diverse locations.

Another technology innovation is liquid air energy storage, which uses electricity to compress air, cool it to liquid phase (-194°C), and store it in a tank. When the liquid air is heated back to a gas and allowed to expand, it turns a turbine-generator and produces electricity. The volume of stored air per megawatt-hour of electricity is substantially smaller relative to traditional compressed air storage. United Kingdom–based Highview Power Storage is developing this technology.

A 5-megawatt liquid air energy storage demonstration facility built by Highview Power Storage. Photo courtesy of Highview Power Storage.

Many compressed air storage developers are considering decommissioned power plants as possible locations. “Ideal sites may have a connection with a transmission line and a water source previously used for plant cooling,” said Westlake. “Using existing infrastructure makes a lot of sense. For example, there’s a large coal plant shutting down in Utah that looks like a contender because it is near underground salt caverns for air storage and has a direct transmission connection to Los Angeles.”

Batteries are also being explored for bulk storage applications. Flow batteries use two liquid electrolytes that are stored separately and flow together in a reaction cell to produce electricity. Like pumped hydro and compressed air storage, they allow power and energy to be scaled separately. Enlarging the storage tanks prolongs the duration of energy output (megawatt-hours), while enlarging the reaction cells increases the power (megawatts).

“One of the strengths of flow batteries is they enable independent adjustments to energy and power, so that you can tailor the system to fit your needs,” said Westlake. Power ratings range from 100 kilowatts to 10 megawatts, with durations of 2 to 8 hours.

More than 20 flow battery companies are developing technologies, some with the assistance of the Pacific Northwest Laboratories, a pioneer in flow battery chemistry. So far, most installed flow batteries have less than 1 megawatt of capacity—far smaller than typical bulk storage facilities. However, deployments have been growing in size. In 2017, two 2-megawatt systems were commissioned in the United States, and two more have been announced for future construction.

Longer term, more speculative technologies include thermal storage, advanced rail, and hydrogen.

“Google X is exploring a large-scale thermal storage concept, one component of which stores heat in molten salt—an approach that is used widely in concentrated solar power plants,” said Pellow. “EPRI’s Innovation Scouts are conducting preliminary due diligence on the concept.”

Advanced rail energy storage moves rocks in specialized rail cars to a higher elevation, using gravity to store potential energy. ARES North America is developing this technology.

Hydrogen is another major area of intensive investigation. One pathway for producing hydrogen gas is electrolysis (splitting water with electricity). Although electrolyzer costs remain high, researchers are working toward lower cost hydrogen generation, and EPRI is tracking the emerging technologies.

“The U.S. National Labs are now actively assessing hydrogen for storage to balance the grid,” said Pellow. “There is already traction in Europe, especially Germany, to use off-peak electric power to generate hydrogen gas to complement renewables.”

Energy arbitrage is not an economically viable application of hydrogen storage under current market conditions, as EPRI research has shown. Rather, a major focus of current research is hydrogen’s potential to integrate different energy sectors, such as renewable generation, transportation, and industrial.

The need for bulk storage has never been greater. The support, flexibility, and responsiveness that storage can potentially provide are crucial to maintain forward momentum in renewables. Strategically placed storage can defer or minimize transmission investment.

That said, high costs for most technologies—and limits on the returns that they can yield—challenge the business case for storage deployment. In a 2016 modeling study on the California and Texas markets, EPRI found that storage can be valuable in systems with high renewable energy levels, but revenues diminish as storage deployment increases.

“Bulk storage technologies have the potential to bring together all the disparate pieces of the future grid, including decentralized, variable renewable energy. They can also support flexible operation of fossil and nuclear power plants,” said Westlake. “They are moving from being just another valuable asset on the grid to becoming a strategic imperative.”

Key EPRI Technical Experts

Matt Pellow, Brittany Westlake